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COVER SHEET FOR TECHNICAL MEMORANDUM

TITLE- Low-Energy 1977 Triple-Planet Flybys With an Inherent Abort Option

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AUTHOR(S)- A. A. VanderVeen

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Multi-Mission Opportunities
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ABSTRACT

A low-energy ballistic triple-planet flyby mission was discovered to be available in January of 1977, in coincidence with the launch window of a Venus flyby opportunity. It is demonstrated that, when used in combination, a quasi free-return abort option exists which cancels almost a year from the primary mission duration. These new missions have lower launch velocity requirements than any previously identified ballistic triple-planet flyby missions. The extraordinary attractiveness of its launch and planetary encounter characteristics suggests that this triple-planet flyby mission be recommended for a primary role in the manned flyby phase of our planetary exploration program.

A multiplicity of mission opportunities is observed to occur during the 1977 time-period, from which other conversions may arise. A possible rescue opportunity is afforded the low-energy triple-planet flyby mission.

Application of segments of this class of triple-planet flyby trajectories to accomplish Mars stopover missions appears attractive. By virtue of the low velocity at Mars encounter as well as at Earth departure and return, these missions could compete with the low-energy conjunction class missions. Such an approach might be applicable in 1983, when the overlapping mission opportunities become available again.

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BELLCOMM, INC.
1100 Seventeenth Street, N.W. Washington, D.C. 20036

SUBJECT: Low-Energy 1977 Triple-Planet Flybys With an Inherent Abort Option - Case 720

DATE: April 24, 1968

FROM: A. A. VanderVeen

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TECHNICAL MEMORANDUM

INTRODUCTION

Previous studies have identified eight families of triple-planet flyby trajectories whose launch opportunities occur in the late 1976/early 1977 time period (1). It was subsequently observed that the launch date of the 1977 Venus flyby mission occurs at about the same time as the launch opportunity of one of the triple-planet flyby missions. Since the launch velocity requirements and available window are considerably less restrictive for the Venus flyby mission than for the triple-planet flybys, it was speculated that one might leave for Venus via the Venus flyby mission profile and, when at Venus, convert to the triple-planet flyby profile by means of a modest velocity impulse. In this manner advantage could be taken of the "easy" launch conditions and, as a bonus, obtain a "free-return" capability until the first Venus encounter. The duration of the free-return mission would be almost a year shorter than that of a completed triple-planet mission.

BACKGROUND

Based upon the limited data available, it first appeared that a disparity of some forty days existed between the Venus passage dates of the two missions. The passage date of the single flyby would have to be pushed back quite a bit later than the reference date (2), in order to coincide with the first Venus passage date for a ballistic triple-planet flyby (1). However, adjustment toward an earlier passage date might be made for the case of the triple flyby by disregarding its first leg ballistic flyby constraint at Venus. In effect, a dual-planet flyby of Mars and Venus, departing from Venus on a predetermined date, would be sought for a return to Earth. The attractiveness of the concept would be manifest by the amount of ΔV required to effect the transfer at Venus and by the degree of degradation of the Venus flyby launch conditions.

Detailed investigation revealed, however, that there exists another group of roundtrip Venus flybys during the same launch window as those of Reference 2, but whose Venus passage dates occur about twenty-five days later, and whose trip durations are some thirty-five days longer; their launch and arrival conditions appear to be quite similar. The 1977 Venus flyby trajectory surface was mapped in detail in the region of the later passage dates, which are more amenable to the triple-planet conversion, so that accurate data would be available for the transfer ΔV calculations and so that favorable trends in mission characteristics could be observed.

With a series of actual Venus free-return flyby trips available for reference, the attempt to find the dual-planet segments from Venus to Earth proceeded. The Venus flyby date was still some fifteen days earlier than that of the triple-planet flyby used as a guide, so the Mars flyby date was sought from ten to fifteen days earlier, and the second Venus date was moved up about five days. Eventually, a successful roundtrip was found, and the transfer ΔV at Venus was calculated to be about 4000 fps. While such a velocity change is a major propulsion requirement, the total velocity requirement of 16,500 for the mission was about the same as that required for injection into the ballistic triple flyby profile.

During the subsequent investigation it was observed that the final earth return date had little influence on the impulsive transfer requirement at Venus*. Thus, a typical earth return date could be chosen, and the earth departure and earth arrival dates for the Venus flyby could be incremented, in turn, to obtain a systematic variation of the transfer characteristics.

A surprising result was obtained. The transfer ΔV requirement approached zero for several trajectory combinations; furthermore, the injection velocity was as low as 14,000 fps. It was now apparent that a new family of ballistic triple-planet flybys had been discovered, whose energy requirements are lower than those previously identified in Reference 1, and whose first leg was common with the first leg of a roundtrip Venus flyby mission.

THE NEW TRIPLE-PLANET FLYBYS

Using the dates of the newly found "convertible" mission, the ballistic flyby constraints were imposed at Venus, Mars, and again at Venus, and the low-energy triple-planet flyby

*The decoupling between the first and second halves of the triple-planet flybys at Mars is apparent also. See Figures 1, 5, 6, and 10 for the effects of variations in launch or arrival dates.

launch window and mission characteristics were investigated. The trajectory surface, mapped in Figures 1-5, shows that ballistic flyby conditions prevail for a launch period of around ten days. (The cutoff of data at the right of these graphs result from failure of the ballistic flyby constraints to be met*.) A nominal mission selected early in the window passes Venus at an altitude of 170 nm and is 720 days long. Specific mission parameters are given in Table 1.

The families of 1977 triple-planet flybys previously found offered four launch windows and two return options for each window. The newly found triple flyby launch window coincides with the second of these four windows, and its second Venus passage date and earth return date agree with those of the late return family. Therefore, it appeared quite likely that an early return family of low-energy triples could also be found. Such was indeed the case, and the family presented in Figs. 6-10 was determined to have similarly attractive planetary characteristics. The first three legs of the nominal trajectory selected are very nearly identical to the 720-day mission, but this 664-day trip takes a "short-cut" and arrives at Earth with a speed of 49,500 fps versus about 39,000 fps for the longer return leg. Its characteristics are also listed in Table 1.

THE FREE-RETURN VENUS FLYBYS

The trajectory surface of the 1977 Venus flyby opportunity, which can be used for free returns, is plotted in Figures 11-13. The terminal dates for which the trajectories would impact Venus are indicated by the shaded area in the lower right-hand corner of the graphs. It is apparent that a wide variation in launch date is permissible without incurring a significant penalty in injection velocity. The nominal trajectory, indicated by the markers on the graphs, demonstrates the results of trade-offs between injection velocity, Venus passage altitude, and the late Venus passage date required to provide the free return feature. The nominal mission parameters are again listed in Table 1.

USE OF THE GRAPHS

The reference mission indicated on Figures 1-13 represents a somewhat arbitrary selection of many possible profiles which incorporate the free-return option. If, for some reason, a different mission profile is desired, the pertinent trajectory characteristics may be determined as in the example given here.

Suppose that a launch delay of five days becomes necessary. The reference point on Figure 1 can be translated five days to the right, shortening the total trip by five days,

*Powered flybys can be employed in these cases, but only a few additional days of launch window can be obtained before the velocity adjustment becomes prohibitive.

but a slight launch advantage is gained, if the trip duration is held to the reference value, so that the earth return date is also shifted five days. The new mission would then have the coordinates of (3165, 3885) on Figure 1. Locating the same point on Figure 2, the Venus passage date of 3298 is found. (It may be observed here that the passage radius is increased from 1.05 to 1.32 Venusian radii, and the periapsis velocity is decreased from nearly 41,000 fps to about 38,500 fps. Changes will also be noted in the passage characteristics of the other planetary encounters.) The Venus passage date of 3298 is now used in Figure 12 along with the new earth departure date of 3165; these dates define the first leg of the modified Venus flyby profile. Locating 3165 on the abscissa and moving upward to the 3298 passage date curve locates the earth return date of 3550 on the ordinate. Changes in the abort-flyby parameters may be noted at the new coordinates in this figure and in the associated earth return characteristics of Figure 13. Since the Earth-Venus leg is common to each mission profile, the launch characteristics may be found in Figure 11, where small variations can be interpreted more easily than in Figure 1.

The curves indicate that a launch delay of ten days incurs an injection velocity penalty of about 1200 fps over the nominal value of 13,900 fps.

MISSION PROFILES

The mission profile of the 720-day low-energy triple-planet flyby is plotted in the conventional manner in Figure 14. To illustrate the differences that exist between the three missions, their profiles were superimposed in a different form in Figure 15, where the heliocentric distance of the spacecraft is plotted as a function of time without regard for its angular position. In this manner the profile differences are immediately apparent, and a few observations of interest can be made regarding specific trajectory parameters.

The tangential nature of the Mars encounter indicates a low passage velocity (17,100 fps). The earth entry speed of the 720-day mission is considerably less than that of the 664-day mission (39,200 fps vs. 49,500 fps), again because of its more tangential approach. The fast, early phase of the Venus flyby mission occurring inside of earth's orbit is followed by a somewhat comparable time spent in a slow trajectory beyond earth's orbit, necessary according to Kepler's areal law, to effect the rendezvous with Earth.

MISSION PLANNING STRATEGIES

When the set of missions discussed here is considered in the light of their conversion possibilities, the triple-planet flyby must be considered as the primary mission. The "common" first leg assumed here is based on "patched conic" approximations and actually breaks down into distinct legs on a refined analysis basis, and a small impulse will be required to convert from one to the other. With this in mind two mission planning strategies become apparent. The single Venus flyby profile may be flown until the Venus encounter, whereupon it is converted to the primary mission profile if everything is still "go", or the primary profile may be flown from launch with the knowledge that the mission may be aborted at Venus at little cost. The choice is controversial, but its influence on overall mission requirements is almost insignificant. Preliminary calculations show that, either way, an impulse of less than 500 fps is required for the conversion; this is of the same order of magnitude as midcourse correction requirements per leg. However, the choice must be made, because a reference trajectory must be available prior to launch. Perhaps psychological considerations will dictate the adoption of the early return Venus flyby as the reference trajectory rather than using an abort philosophy. It should be kept in mind that although either reference trajectory would ideally be a free return, in reality midcourse corrections will be required in any case.

Figure 16 illustrates the differences between flyby profiles at Venus. Both involve near-polar routes over the lightside region, although for the triple-planet mission, the flyby would be classified as a twilight type.

SIGNIFICANCE OF MULTI-MISSION OPPORTUNITIES

A multiplicity of mission opportunities occur during 1977 which provide potential conversion possibilities, limited largely by the imagination of the investigator.

The Venus flyby, used in conjunction with either of the low-energy triple-planet flybys, was demonstrated to provide either a quasi free-return abort option. Also discussed briefly was the return option that exists between these two triple-planet flybys, whereby the 720-day trip may be shortened by two months at the expense of a higher velocity earth entry.

Eight other families of triple-planet flybys exist with their sequence of opportunities beginning in late 1976 and ending in April of 1977 (1). During the first of these windows a dual-planet flyby of Venus and Mars is available (3), which is very similar to the triples, except that the second Venus passage is omitted.

Cursory examination of Earth-Venus and Venus-Earth trajectories (4) indicates that a high-energy (22,000 fps injection velocity) Venus flyby is available departing in November of 1977, which could rendezvous with a vehicle on the triple flyby profile in the vicinity of Venus. This flight has a duration of 380 days and returns with an entry velocity of 45,000 fps about forty days earlier than the 720-day triple flyby mission. If it were necessary, this flight opportunity could be used to replenish some critical shortage aboard the spacecraft, furnish medical aid, or otherwise perform some sort of rescue function.

Figure 17 illustrates schematically the planetary flyby missions that are available during the 1977 time-frame. This figure also illustrates the stopover potential at either Venus or Mars that can be achieved by means of trajectory conversion. Venus stopovers of twenty or thirty days are immediately apparent from the first two Venus flyby profiles, the first of which requires only 11,800 fps injection velocity from Earth. A fifteen to twenty day stopover at Mars is available by using the low-energy triple-planet flyby outbound legs and returning via the inbound legs of the D family. By virtue of the low Mars encounter velocity the deboost and boost velocities for a low altitude circular orbit would be just over 10,000 fps each, making such a mission competitive with the conjunction class missions.

The powered flyby of Venus, used to achieve a multi-planet flyby mission with an inherent free-return abort capability (the original object of this investigation), is also available during the 1977 time-frame and looks quite promising from the standpoint of total ΔV requirements.

CONCLUSIONS AND RECOMMENDATIONS

The newly discovered pair of low-energy triple-planet flybys available in early 1977 offer an extremely attractive opportunity to explore our neighboring planets via the manned flyby mode. The attractiveness of this opportunity is due not only to the "easy" launch conditions that prevail, but because of the fortuitous coincidence of a Venus flyby opportunity which provides the option of a free-return from Venus early in the mission. Such an overlapping of mission launch windows will not be available again until 1983.

While the application of the low-energy triple-planet flyby trajectories to Mars stopover missions may be largely academic for 1977, it should be investigated in detail for the 1983 and subsequent opportunities. Such a mission appears to be competitive with the conjunction class missions in terms of total ΔV while the trip durations are significantly shorter.

The accidental discovery of the low-energy pair of triple-planet flybys and their possible application to Mars stopover missions demonstrate that not all of the attractive planetary mission opportunities have been exposed, as one is wont to believe.

A recommendation was made by North American Aviation (5) that the 1976 dual-planet flyby and a 1977 triple-planet flyby be adopted as the primary and secondary manned space-mission opportunities for a near-future planetary exploration program. In light of these new findings, it is recommended that the low-energy free-return triple-planet flyby in January of 1977 assume the role of primary mission. The backup role can be assigned to the triple flyby available for launch in mid-February, if one is necessary.

A. A. VanderVeen

1013-AAV-sjh

Attachments

BELLCOMM, INC.

REFERENCES

1. VanderVeen, A. A., "Families of 1977 Triple-Planet Flybys", Bellcomm Memorandum for File dated June 6, 1967.

2. "Manned Mars and/or Venus Flyby Vehicle Systems Study, Final Report", North American Aviation, Inc., Report #SID65-761-2, prepared under NASA contract NAS9-3499, 1965.

3. London, H. S., VanderVeen, A. A.,"Existence of a Favorable 1976 Dual-Planet Ballistic Flyby", Bellcomm Memorandum for File dated February 14, 1967.

4. Planetary Space Flight Handbook, Vol. 3, NASA SP-35, prepared for the George C. Marshall Space Flight Center, 1963.

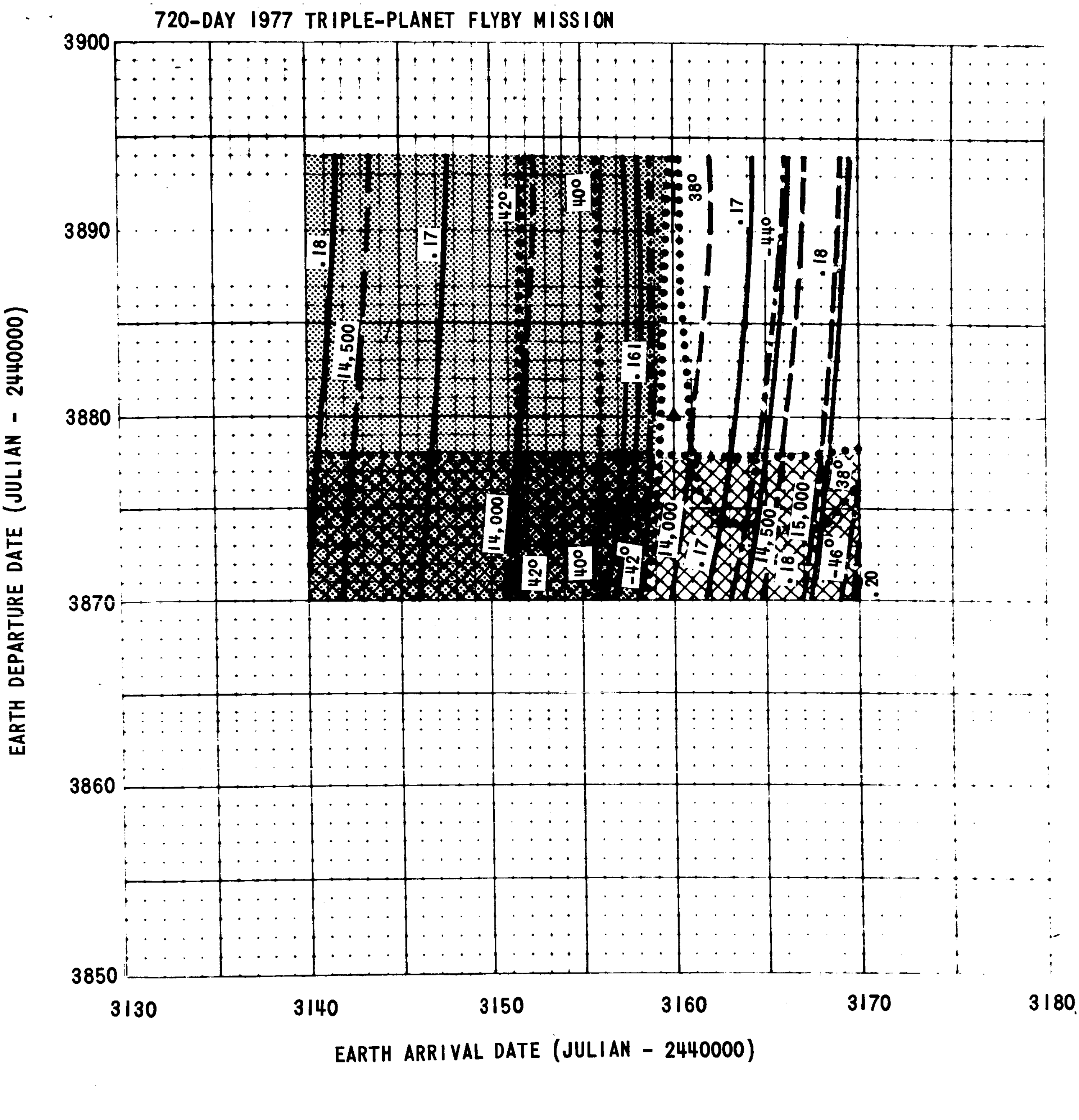
5. "A Study of Manned Planetary Flyby Missions Based on Saturn/Apollo Systems", North American Aviation, Inc., Report #SID 67-549-2, prepared under NASA contract NAS8-10825, 1967.

TABLE 1

NOMINAL MISSION CHARACTERISTICS

EVENT	DATE (Julian)	DATE (Calendar)	V_∞ (Emos)	PASS RAD. (P.R.)	PERI-V (FPS)	INJ/ENT V (FPS)
720-day Triple-Planet Flyby						
Earth Dep.	244 3160	17 Jan 77	0.1625			13,900
Venus Pass	244 3295	1 Jun 77	0.2466	1.051	40,700	
Mars Pass	244 3505	28 Dec 77	0.1455	3.072	17,100	
Venus Pass	244 3739	19 Aug 78	0.2414	1.051	40,400	
Earth Arr.	244 3880	7 Jan 79	0.1549			39,200
664-day Triple-Planet Flyby						
Earth Dep.	244 3160	17 Jan 77	0.1626			13,900
Venus Pass	244 3295	1 Jun 77	0.2467	1.054	40,700	
Mars Pass	244 3505	28 Dec 77	0.1456	3.055	17,100	
Venus Pass	244 3739	19 Aug 78	0.2425	5.944	27,400	
Earth Arr.	244 3824	12 Nov 78	0.3452			49,500
Venus Flyby						
Earth Dep.	244 3160	17 Jan 77	0.1617			13,900
Venus Pass	244 3295	1 Jun 77	0.2455	1.104	40,000	
Earth Arr.	244 3546	7 Feb 78	0.2963			46,300

Note: The minor discrepancies between 'common" legs are due to the incremental stepping of end-dates in the tabular data.



HYPER. EXCESS VELOCITY (EMOS)
INJECTION VELOCITY (FT/SEC)
RIGHT ASCENSION (DEG)
DECLINATION (DEG)
IMPACT AT FIRST VENUS ENCOUNTER
IMPACT AT SECOND VENUS ENCOUNTER
NOMINAL REFERENCE MISSION

FIGURE I - EARTH DEPARTURE CHARACTERISTICS

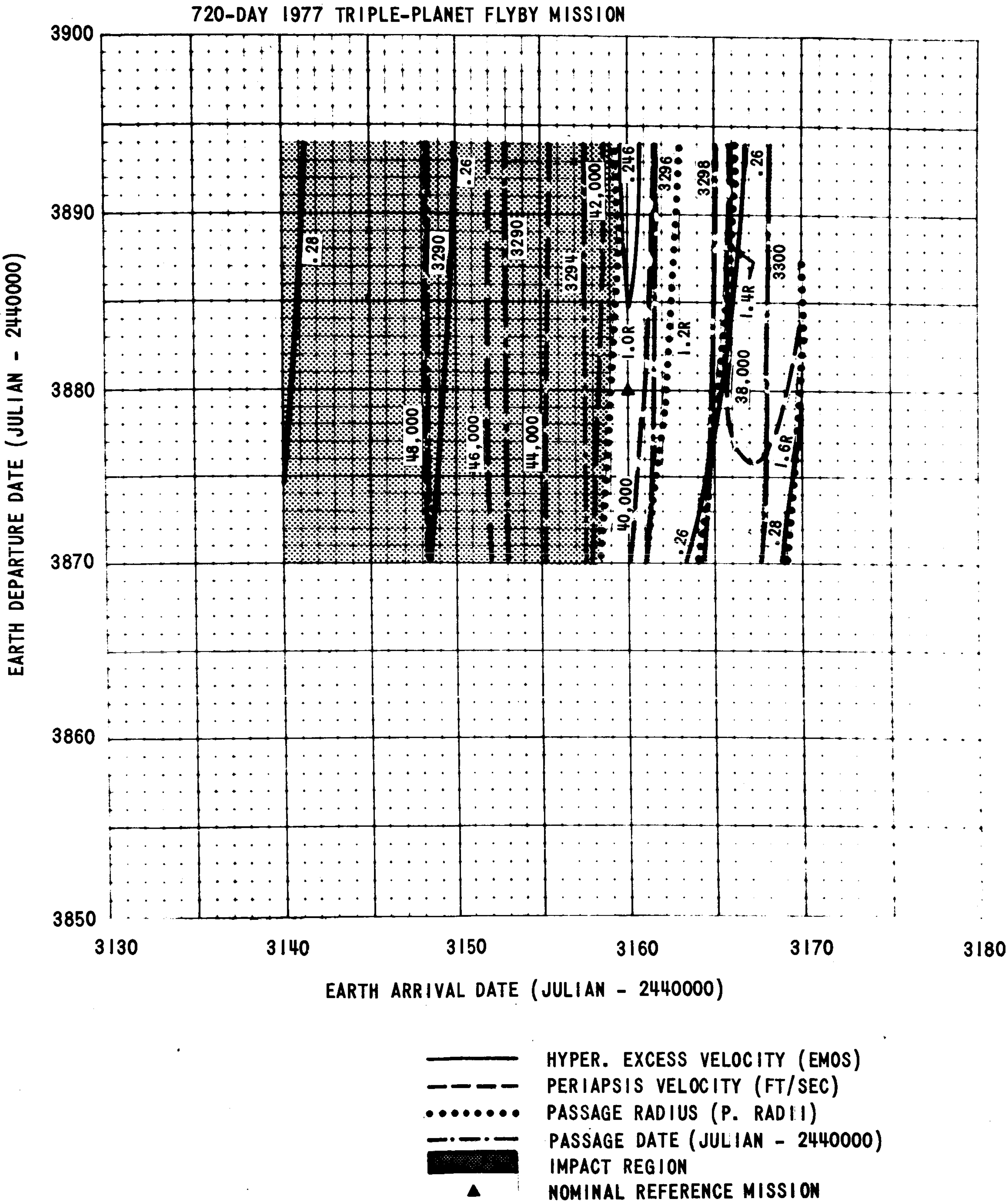
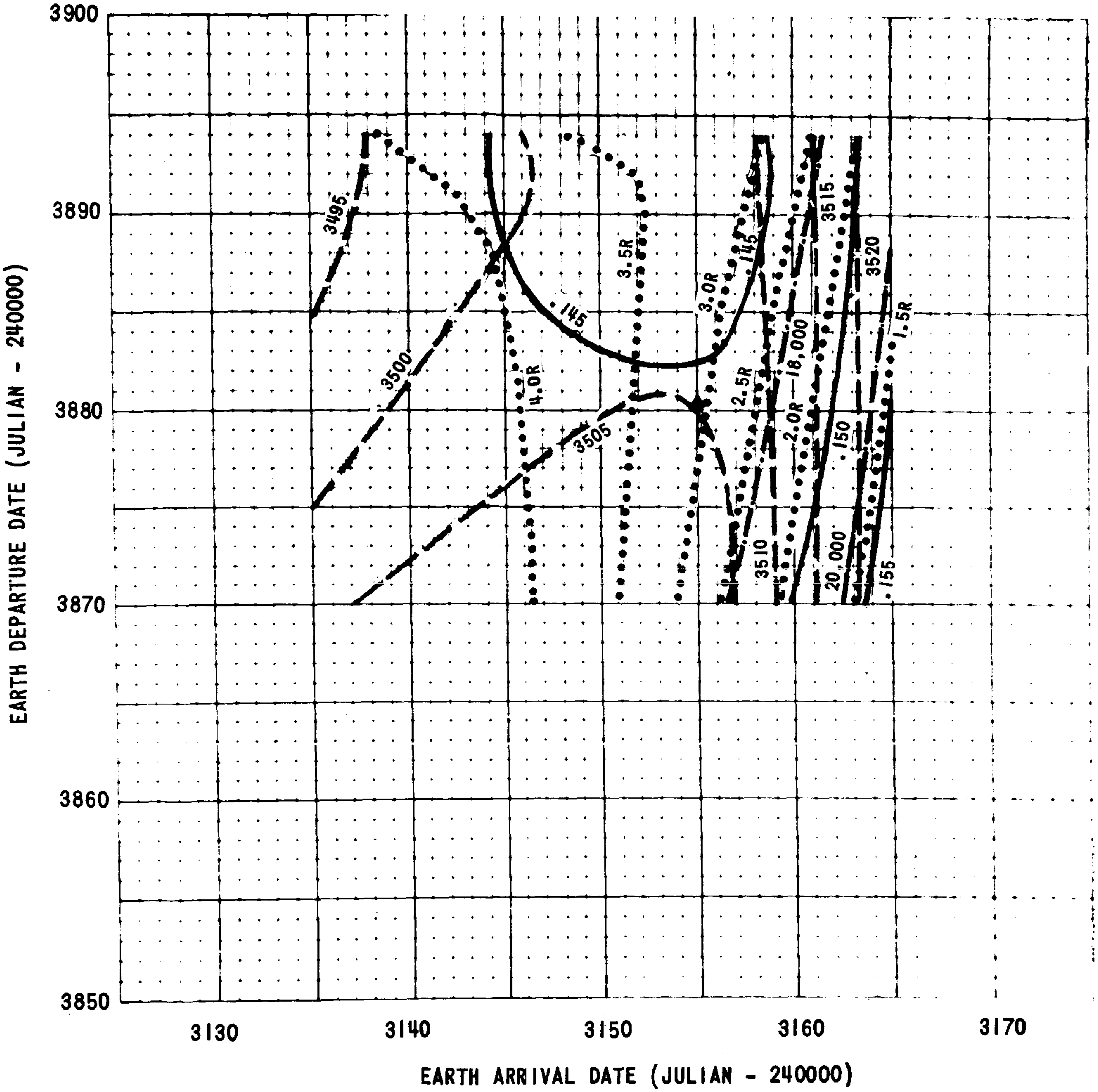


FIGURE 2 - FIRST VENUS PASSAGE CHARACTERISTICS

720-DAY 1977 TRIPLE-PLANET FLYBY MISSION



HYPER. EXCESS VELOCITY (EMOS)
PERIAPSIS VELOCITY (FT/SEC)
PASSAGE RADIUS (P. RADII)
PASSAGE DATE (JULIAN - 2440000)
▲ NOMINAL REFERENCE MISSION

FIGURE 3 - MARS PASSAGE CHARACTERISTICS

720-DAY 1977 TRIPLE-PLANET FLYBY MISSION

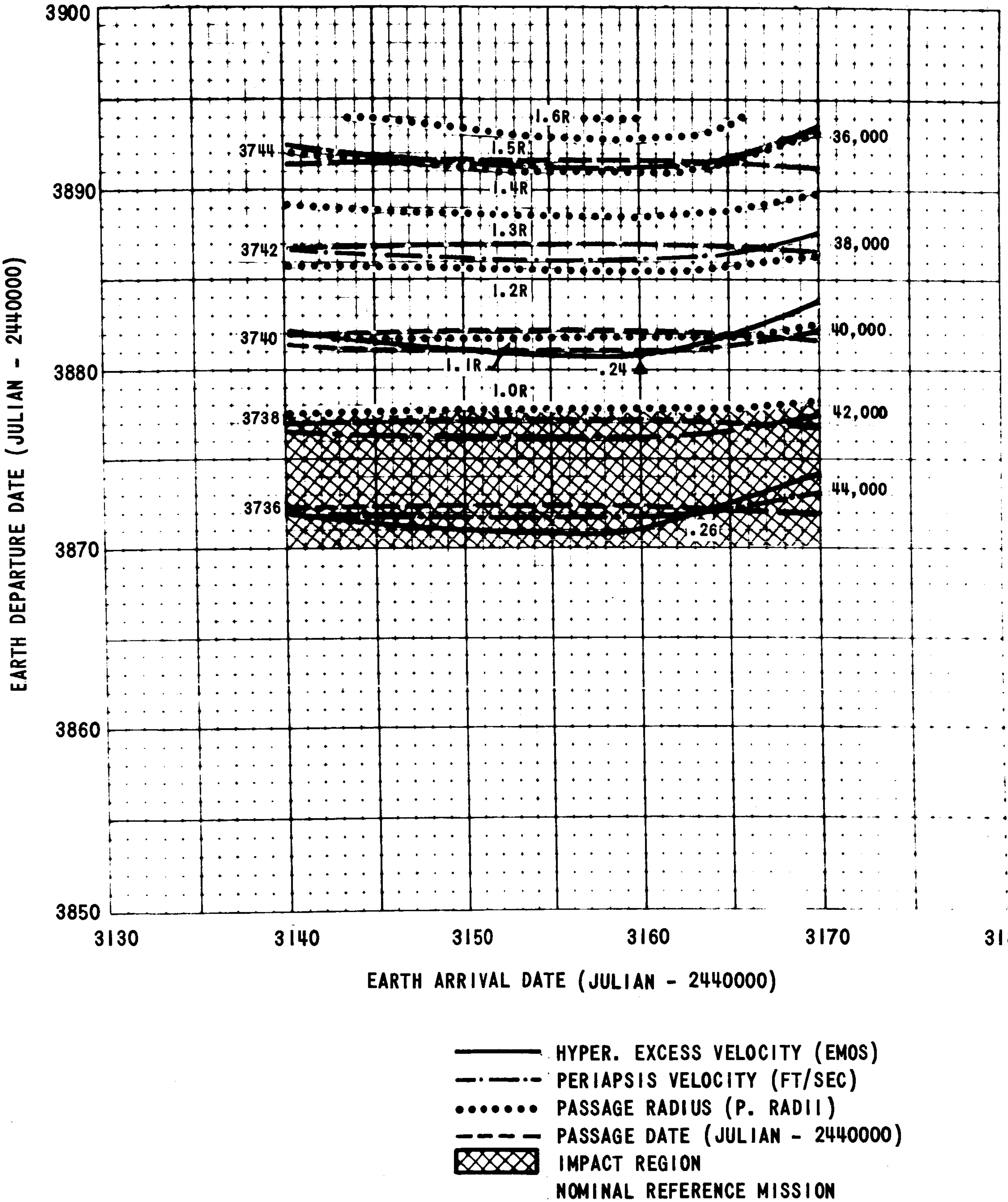


FIGURE 4 - SECOND VENUS PASSAGE CHARACTERISTICS

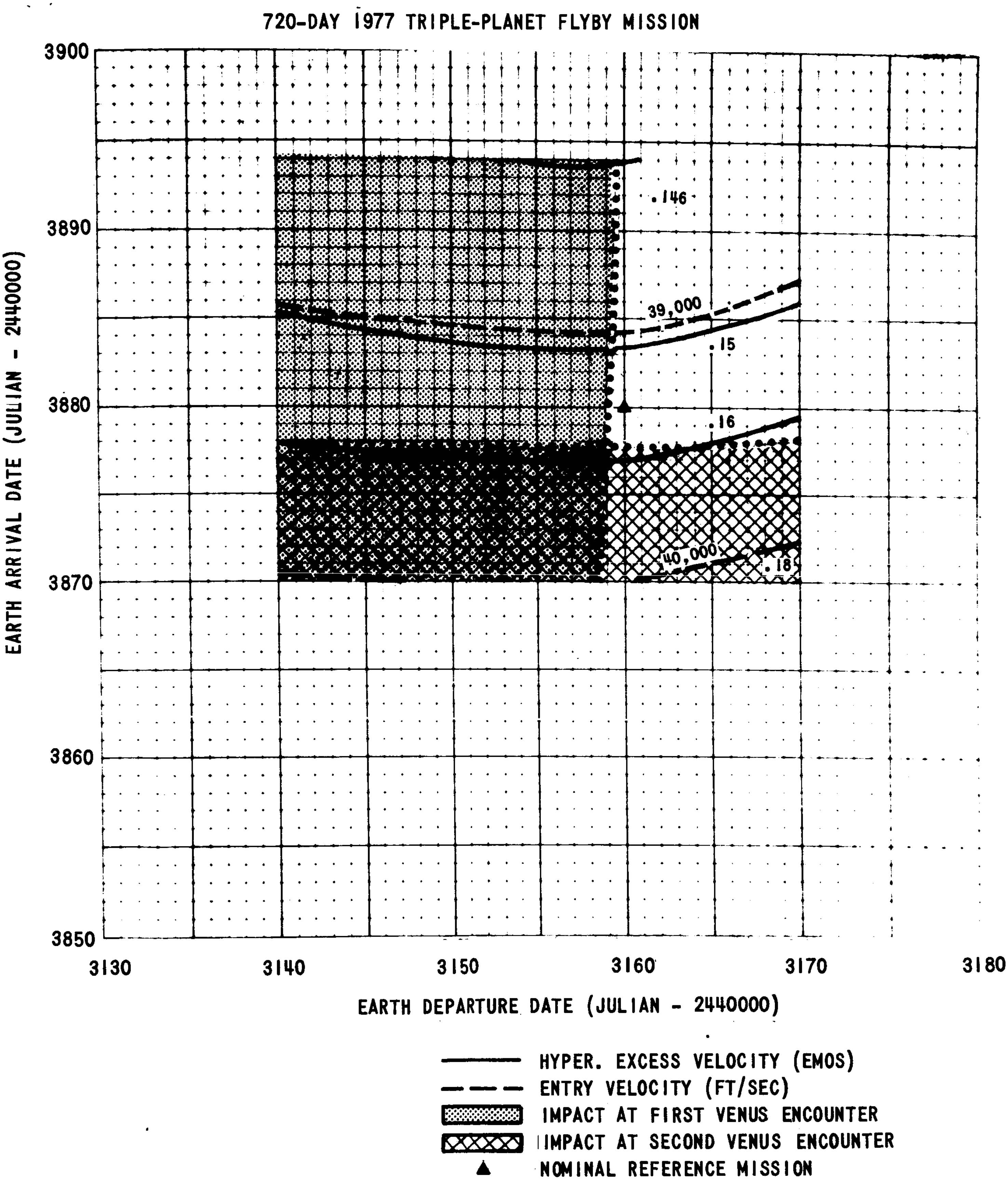


FIGURE 5 - EARTH ARRIVAL CHARACTERISTICS

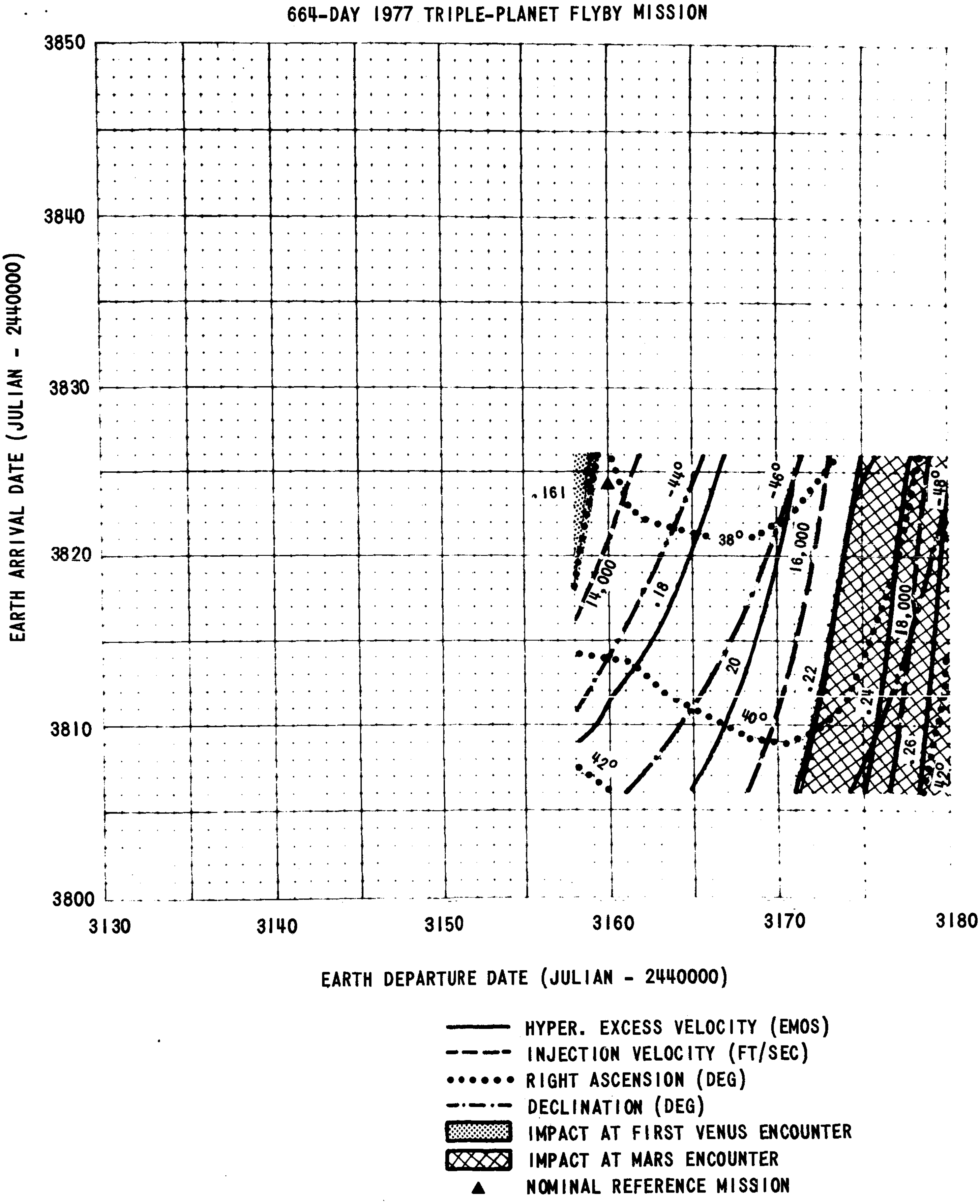


FIGURE 6 - EARTH DEPARTURE CHARACTERISTICS

664-DAY 1977 TRIPLE-PLANET FLYBY MISSION

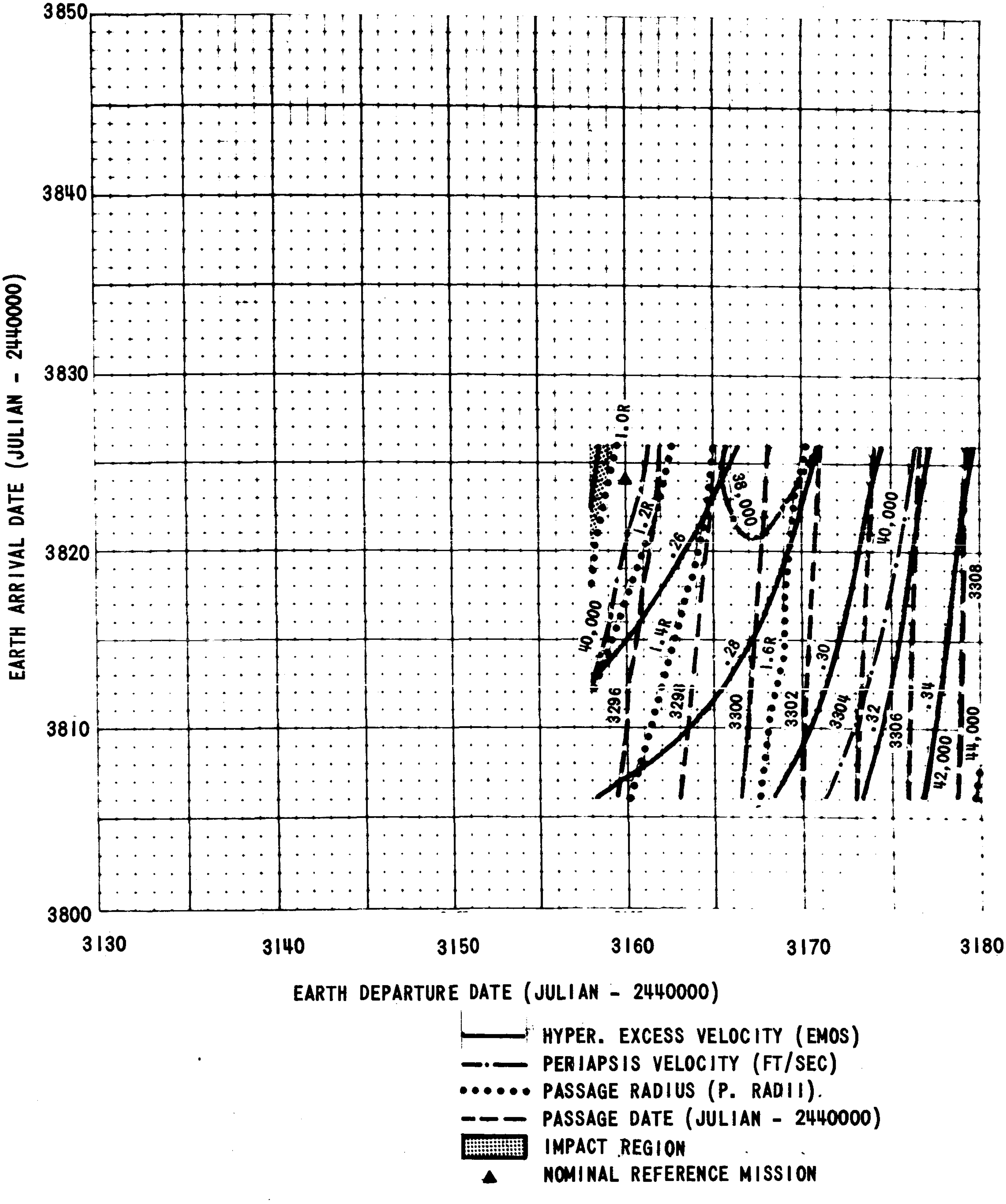


FIGURE 7 - FIRST VENUS PASSAGE CHARACTERISTICS

664-DAY 1977 TRIPLE-PLANET FLYBY MISSION

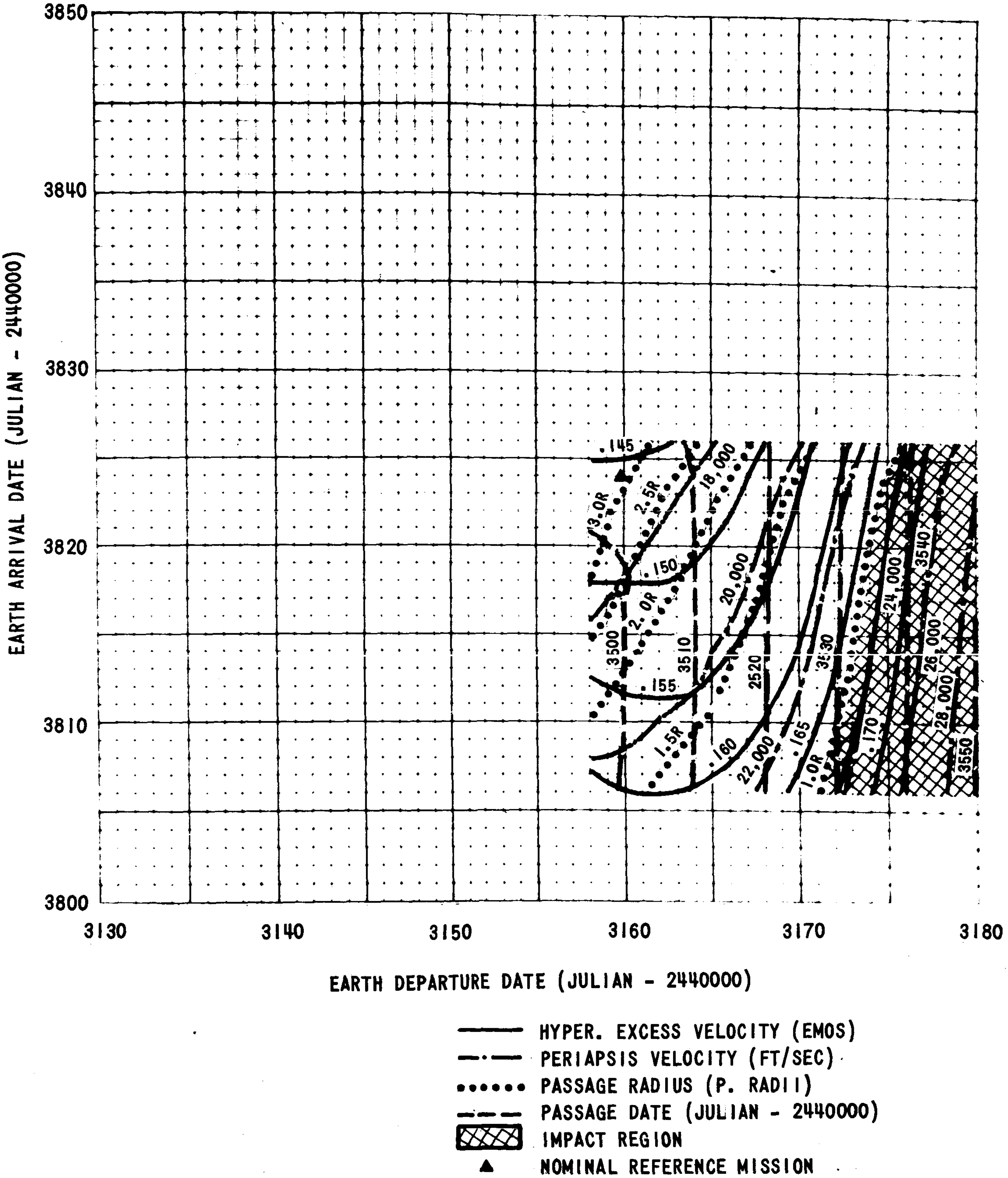


FIGURE 8 - MARS PASSAGE CHARACTERISTICS

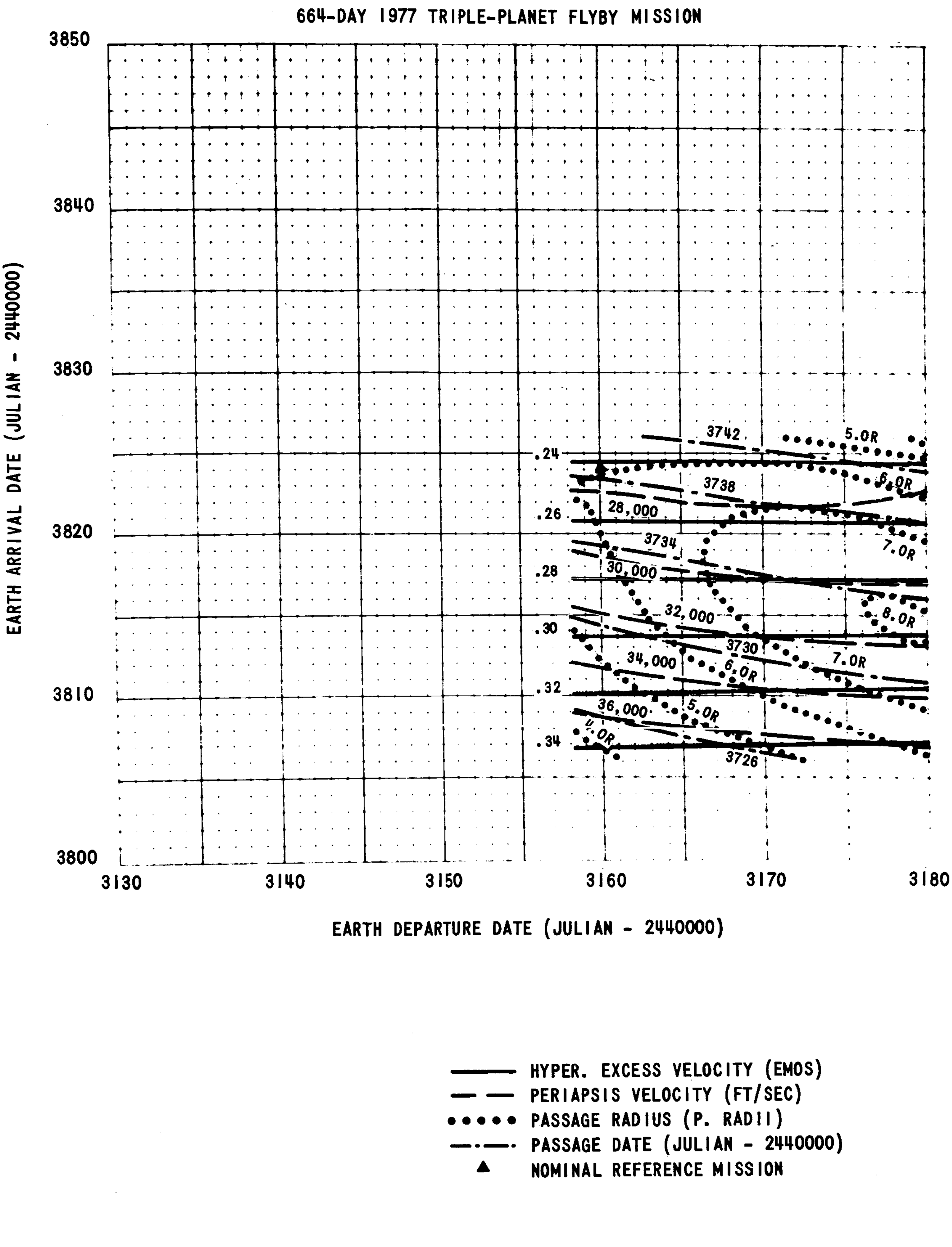


FIGURE 9 - SECOND VENUS PASSAGE CHARACTERISTICS

664-DAY 1977 TRIPLE-PLANET FLYBY MISSION

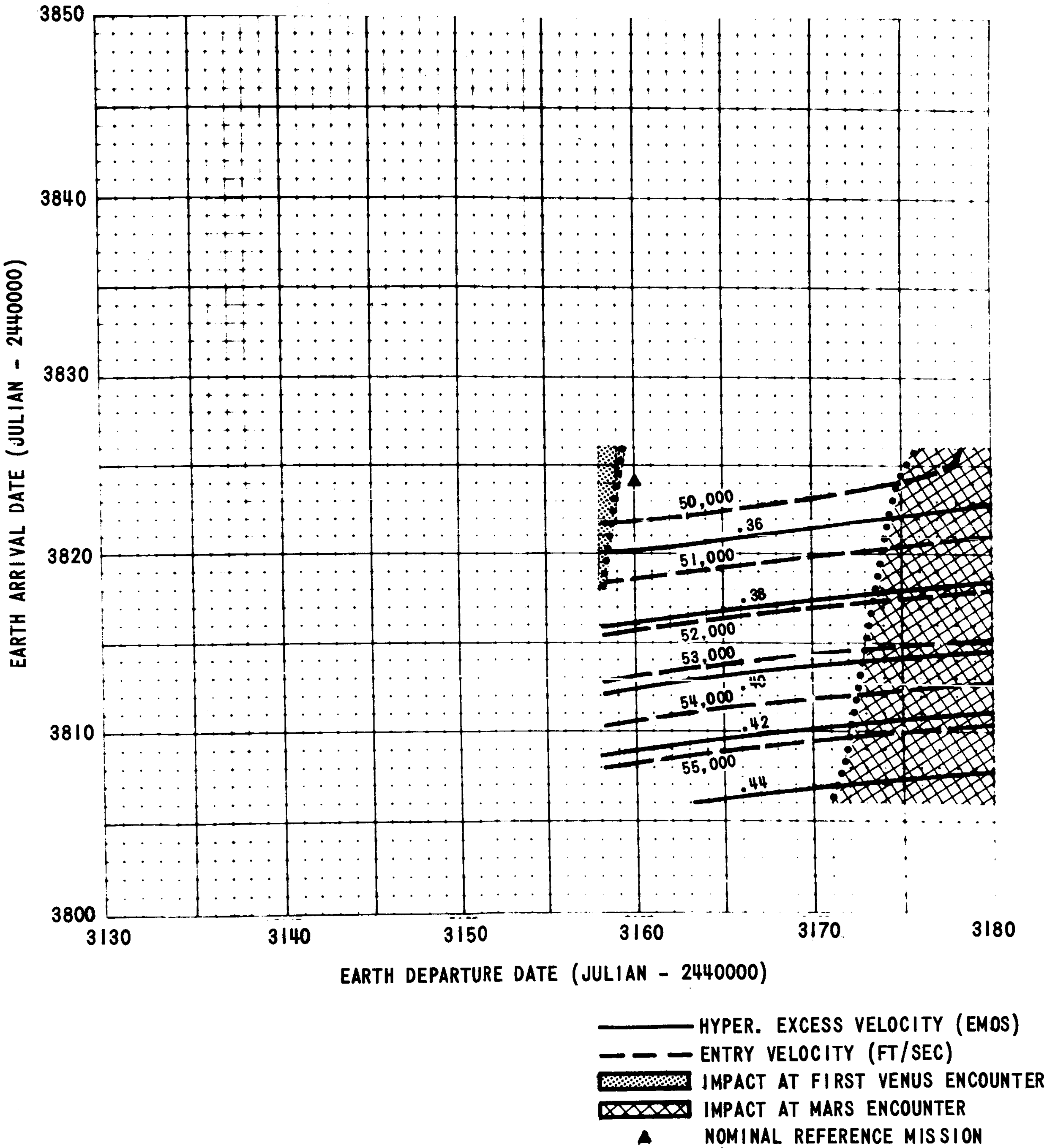


FIGURE 10 - EARTH ARRIVAL CHARACTERISTICS

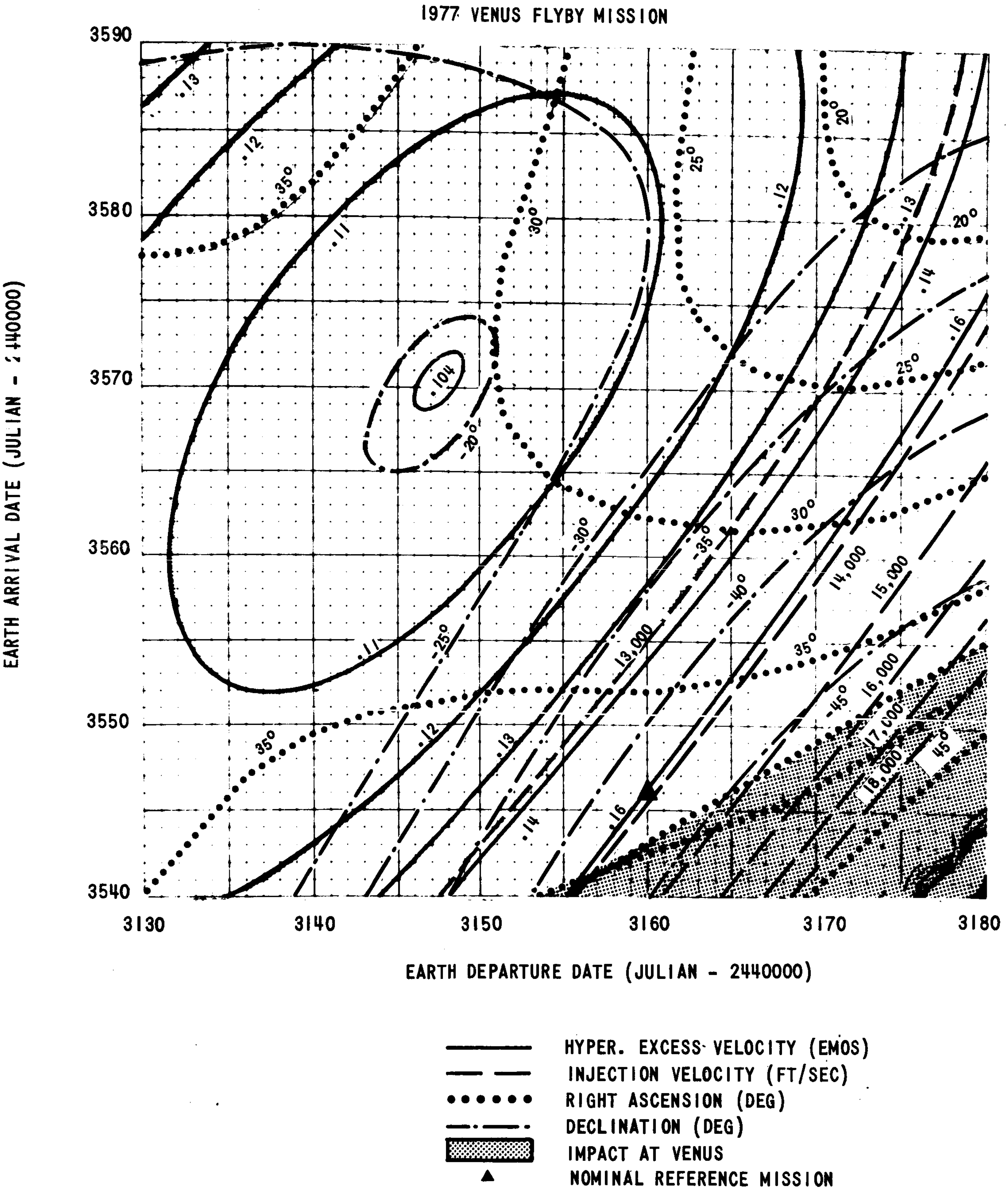


FIGURE 11 - EARTH DEPARTURE CHARACTERISTICS

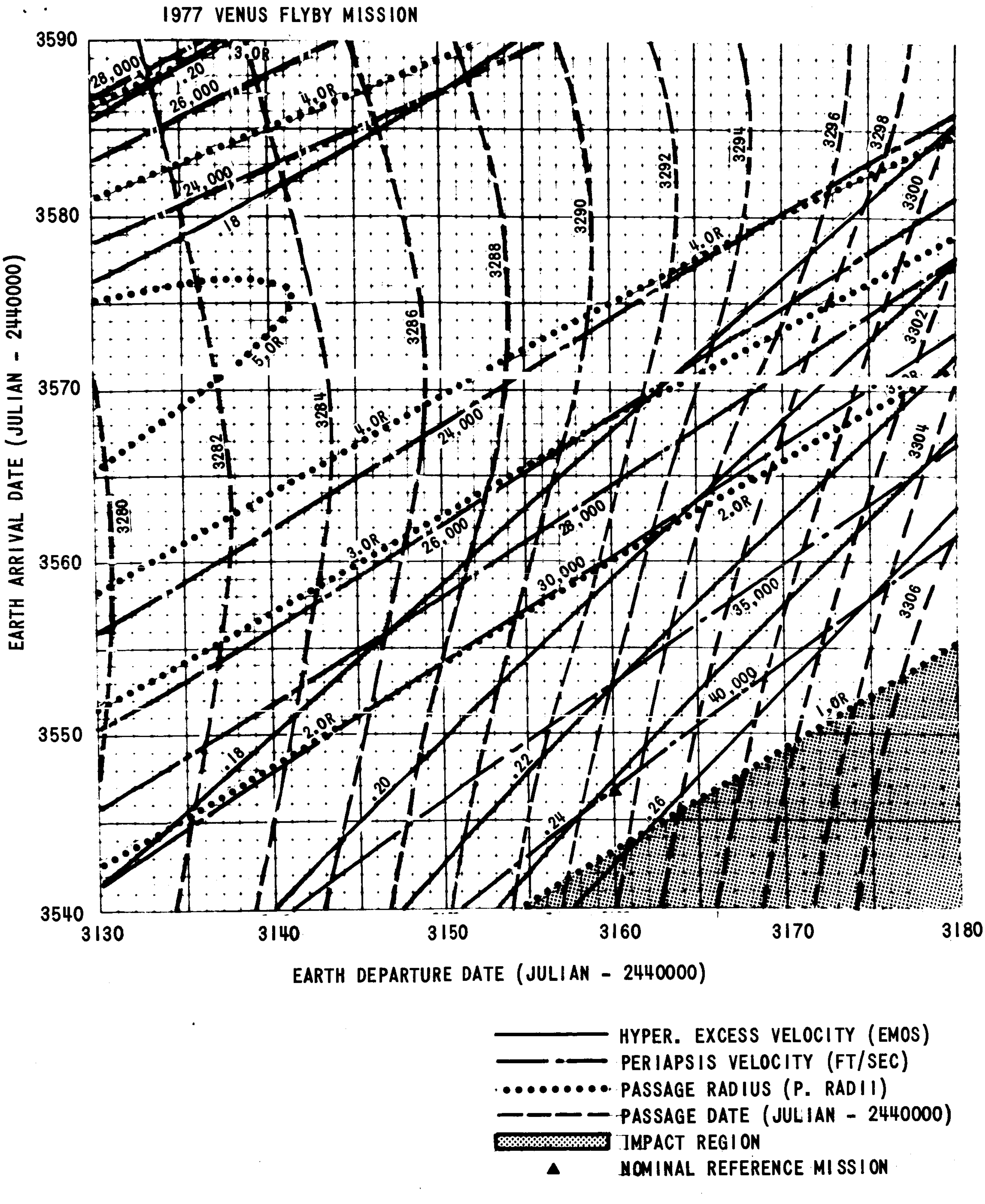


FIGURE 12 - VENUS PASSAGE CHARACTERISTICS

1977 VENUS FLYBY MISSION

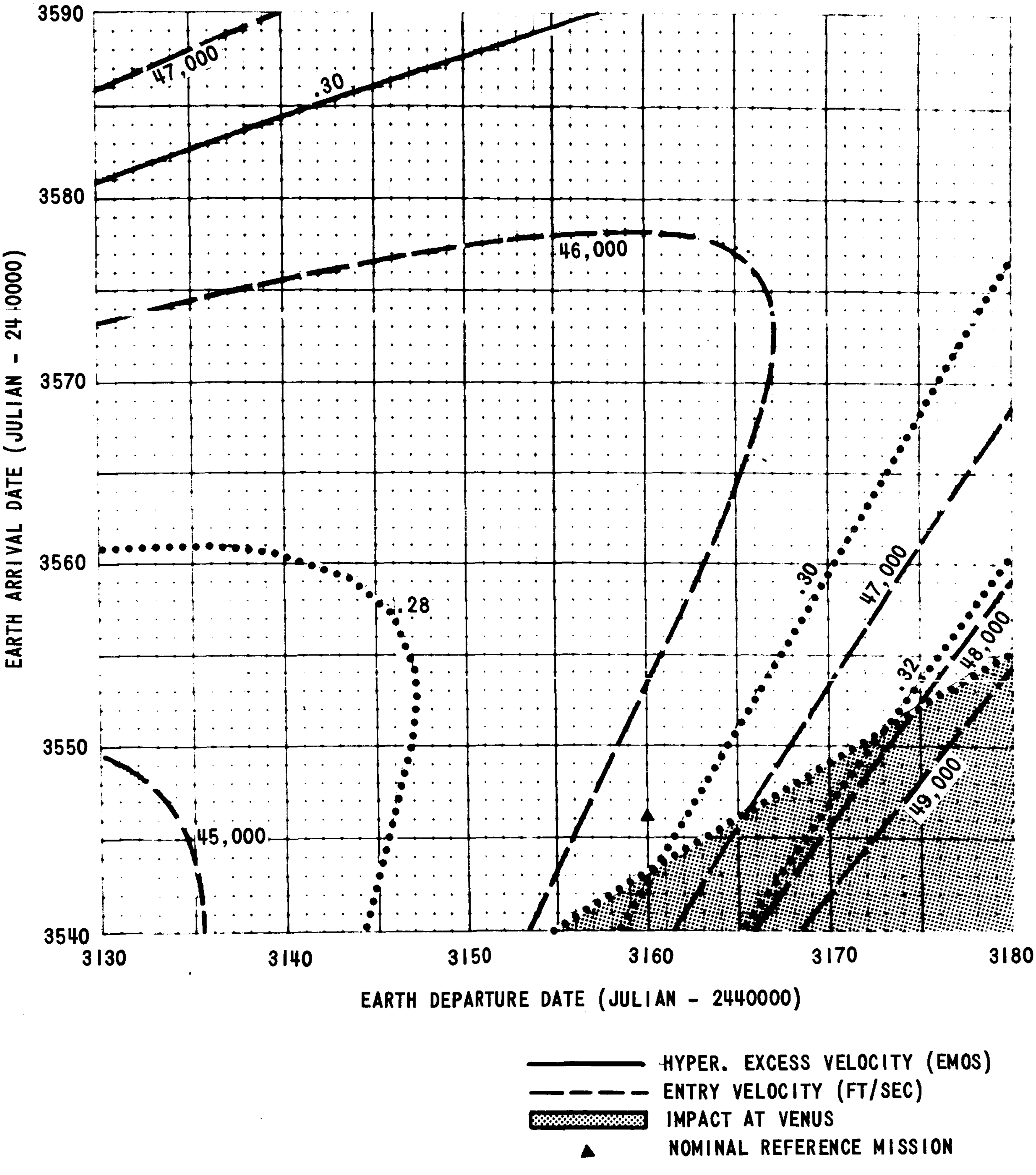


FIGURE 13 - EARTH ARRIVAL CHARACTERISTICS

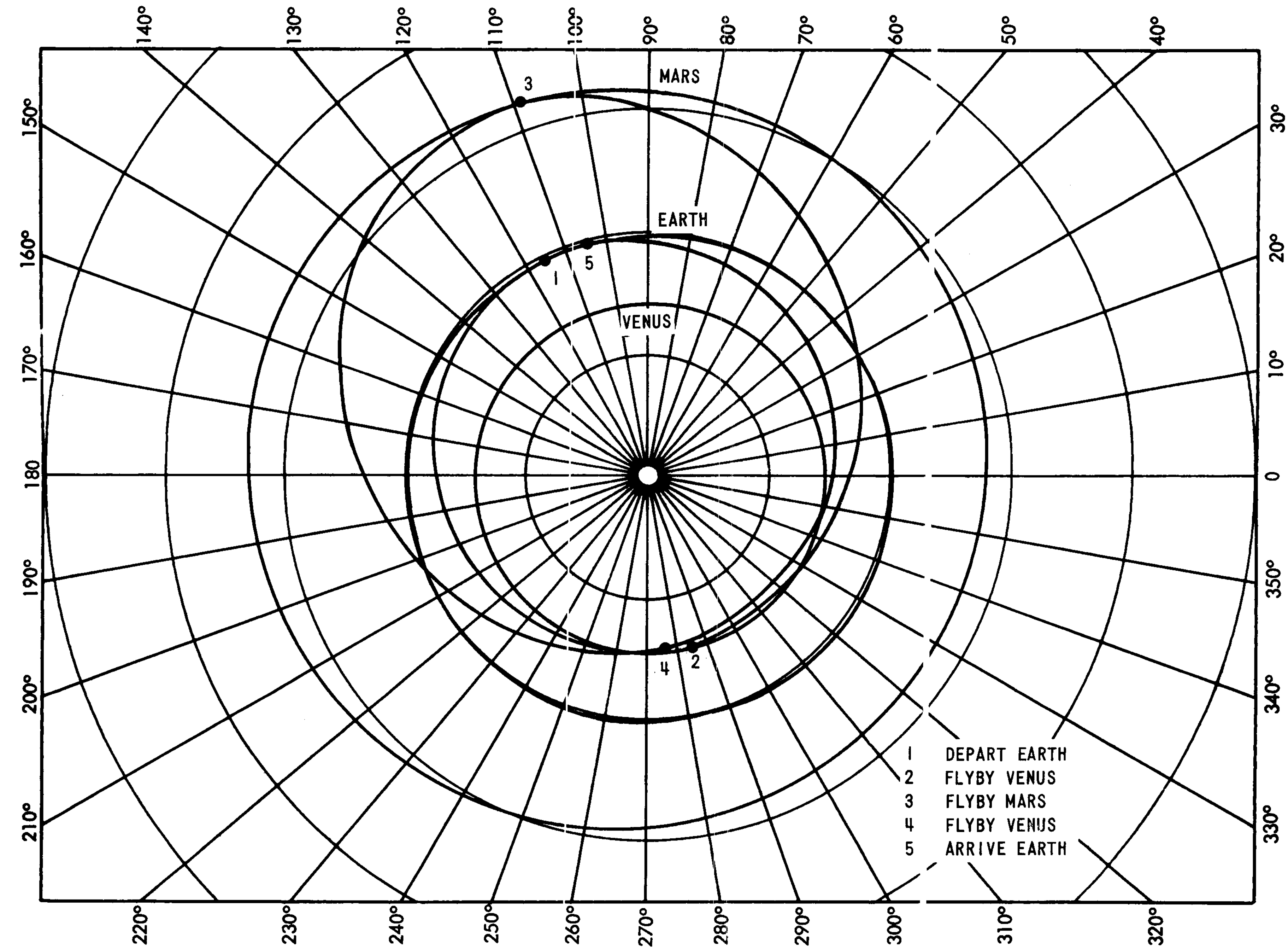


FIGURE 14 - MISSION PROFILE OF THE 720-DAY 1977 TRIPLE-PLANET FLYBY MISSION

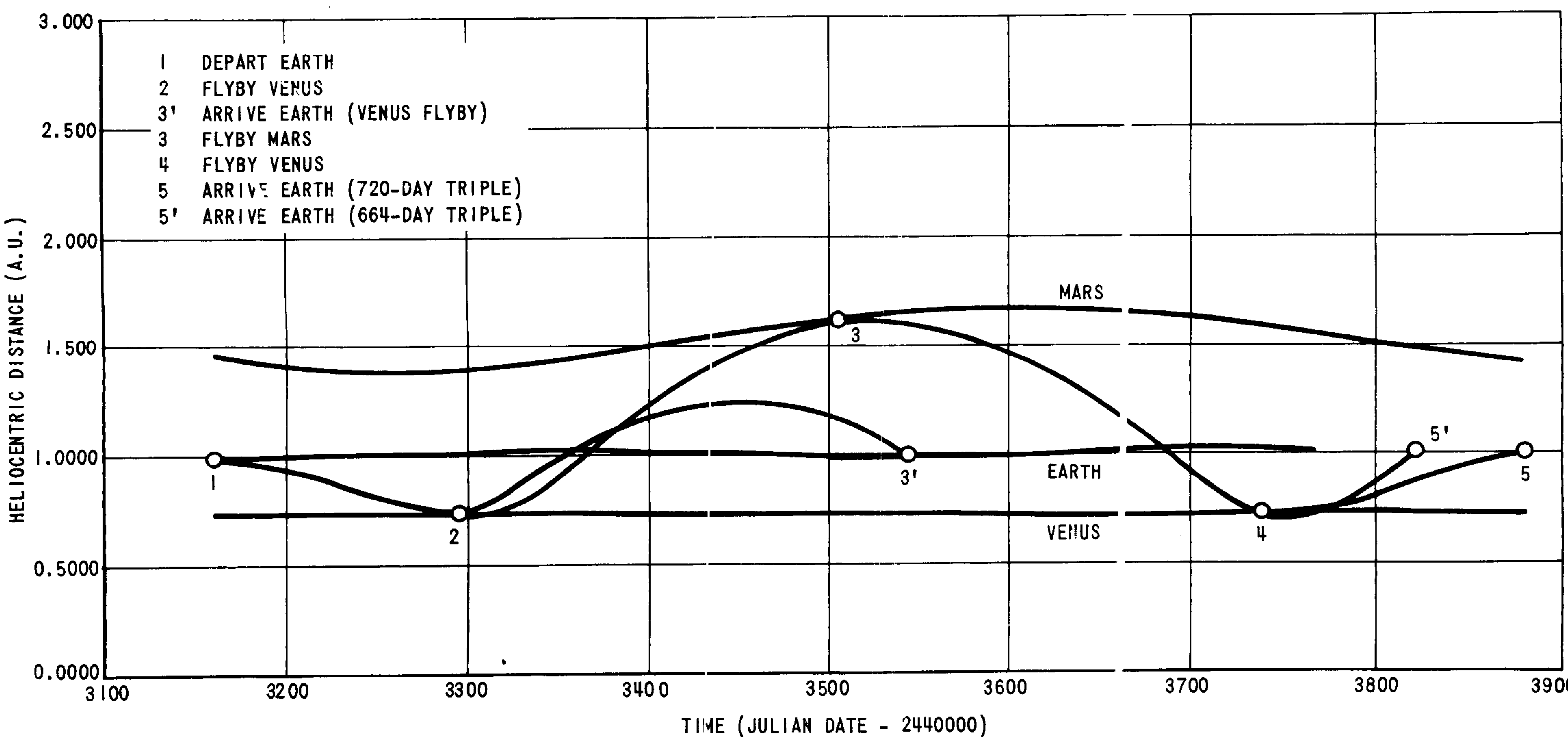


FIGURE 15 - DISTANCE vs. TIME PROFILES OF THE 664-DAY AND 720-DAY 1977 TRIPLE-PLANET FLYBY MISSIONS AND THE 1977 VENUS FLYBY MISSION

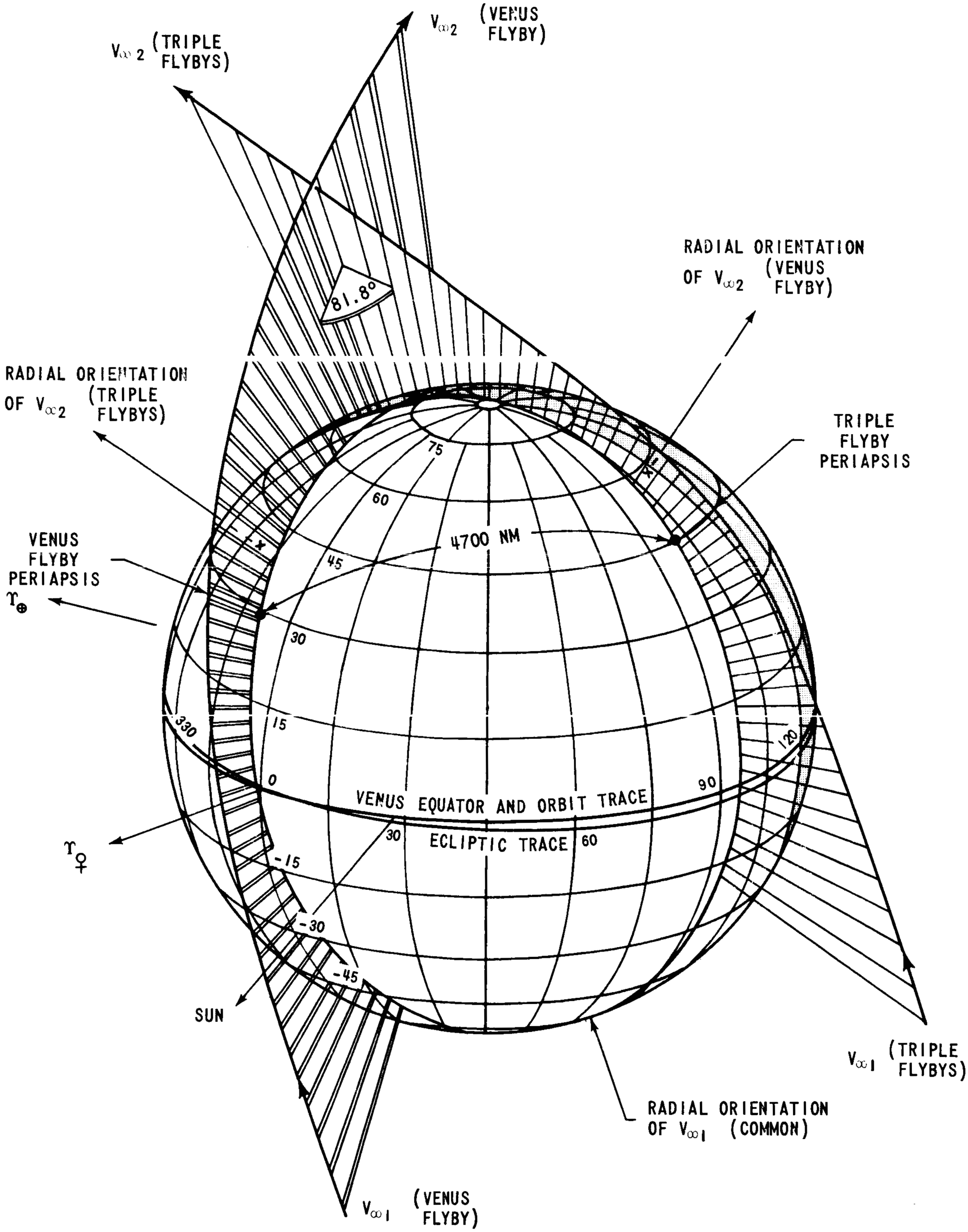


FIGURE 16 - DIFFERENCES BETWEEN THE VENUS FLYBY CHARACTERISTICS OF THE TRIPLE-PLANET FLYBYS AND THE FREE-RETURN FLYBY AT THE FIRST VENUS ENCOUNTER

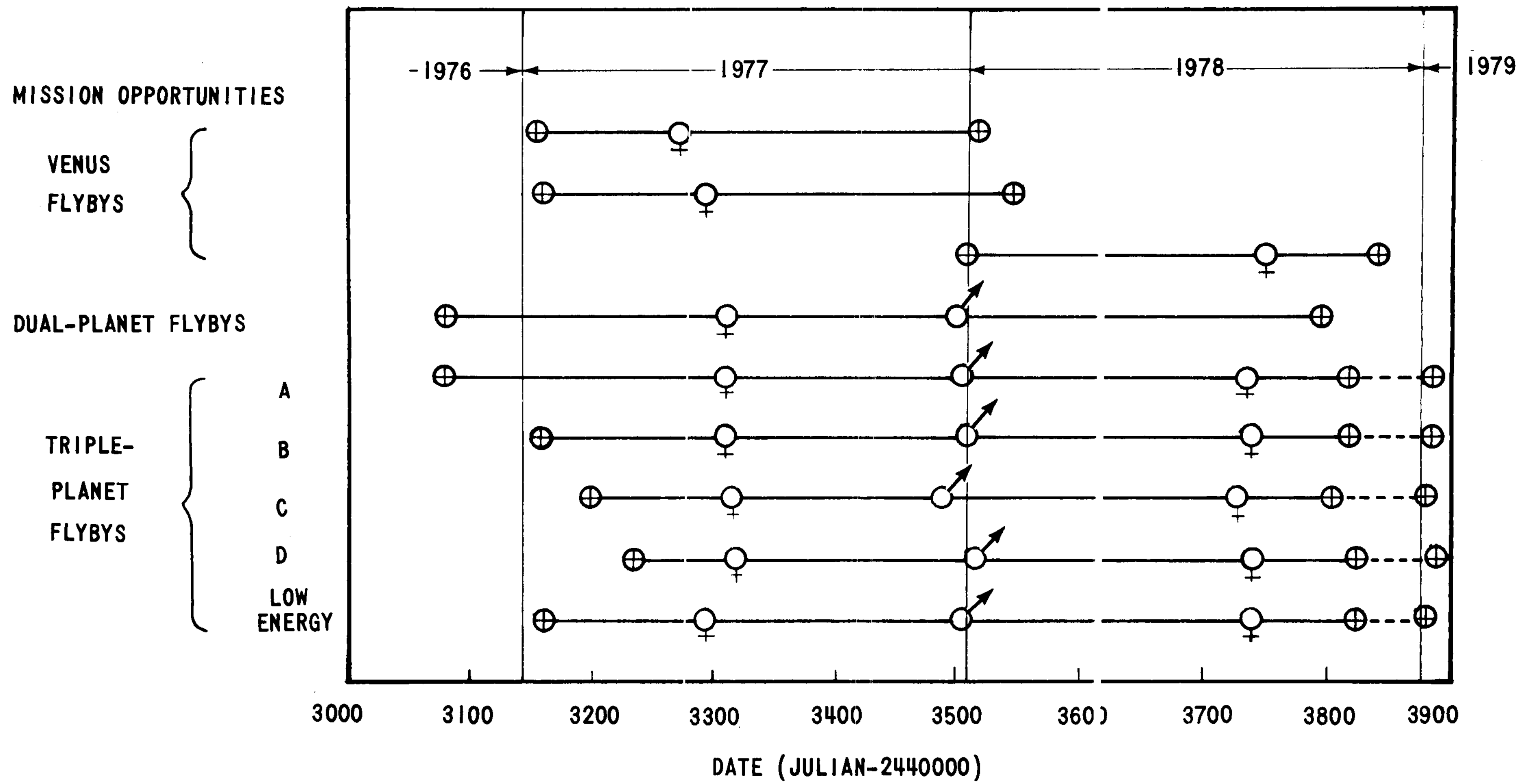


FIGURE 17 PLANETARY FLYBY MISSIONS AVAILABE IN 1977